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User's Guide to the Regeneration Establishment Model—a Prognosis Model Extension

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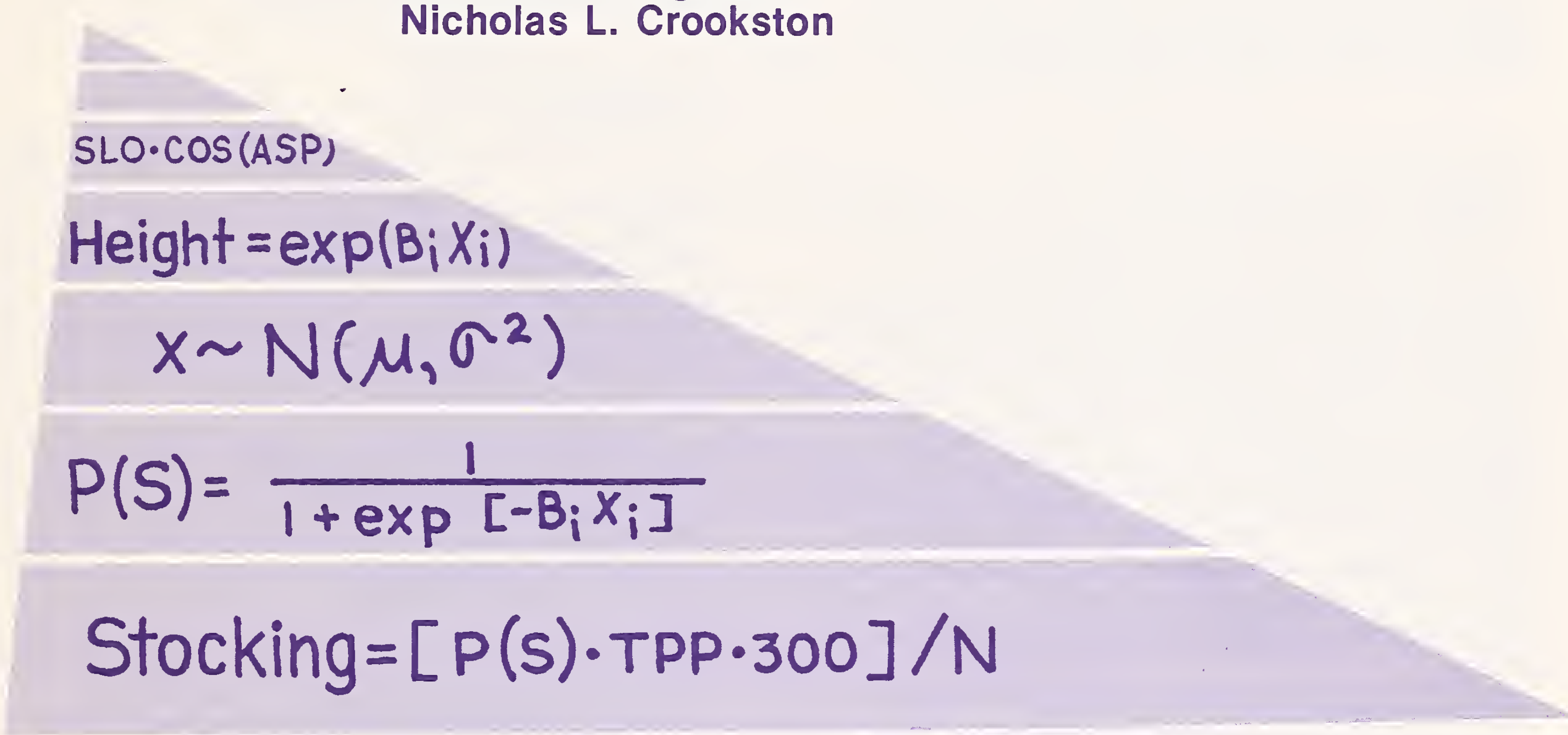

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RESEARCH SUMMARY

This extension to the Prognosis Model predicts regeneration resulting from harvesting and site preparation operations in the Northern Rocky Mountains. Version 1.0 of the Regeneration Establishment Model covers the grand fir-cedar-hemlock ecosystem which includes 10 coniferous species. It represents regeneration from both even-aged and uneven-aged silvicultural systems. The Regeneration Establishment Model is used as a submodel to Version 5.0 of the Prognosis Model. The Prognosis Model contains several new representations of growth rates for small trees that improve its realism for early stand development. Stand projections from one rotation through the next are now possible, enabling forest managers to assess future productivity of the new stand, coupled with intermediate stand density control, if desired. Discussed are model characteristics, prescription options, program control, and regeneration summaries, each with accompanying examples.

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INTRODUCTION

Regenerating cutover areas is perhaps the most critical phase in the life of a stand because productivity lost by poor stocking or delays in obtaining stocking can never be regained. The time needed to regenerate the stand, number of seedlings, and species composition of the new stand constrain management of the stand throughout its life. The National Forest Management Act of 1976 specifies a time frame for obtaining adequate stocking and State forestry practices acts have recognized the need to set stocking standards. Corporate and private landowners also realize the necessity of restocking their forests following harvest operations.

The chances of achieving a regeneration goal depend on many factors, only some of which the manager can control. Sometimes the most carefully executed plans fail and in other circumstances regeneration appears without any effort. Managers need to know which of several regeneration prescriptions has the best possibility of achieving their goal. The Regeneration Establishment Model, an addition to the Prognosis Model (Stage 1973; Wykoff and others 1982), is a tool land managers can use to forecast the results of silvicultural prescriptions for both even-aged and uneven-aged stands. The combined Regeneration Establishment/Prognosis Model can be used to evaluate expected results of regeneration prescriptions and to project future stand development. New areas of applicability include the following circumstances:

- In a stand about to be harvested, to determine if one or more prescriptions meets the regeneration objective.
- In a stand already harvested, to evaluate the need to augment existing stocking.
- As a standard of comparison—either to evaluate past performance or to set future regeneration goals.
- To establish harvesting schedules.
- To evaluate regional timber resources.
- Other forest uses in the areas of wildlife, water, esthetics, etc.

Version 1.0 of the Regeneration Establishment Model becomes available with Version 5.0 of the Prognosis Model. The Prognosis Model has been enhanced to more accurately predict growth of seedling-to-sapling size trees. Growth rates of small trees in Version 5.0 of the Prognosis Model now are calculated by functions that are more sensitive to effects of stand density on diameter increment of trees less than 3.0 inches (7.6 cm) diameter at breast height (d.b.h.). Although there are other improvements in Version 5.0, procedures for using the system described by Wykoff and others (1982) still apply.

Predicting New Tree Records

The Regeneration Establishment Model simulates the regeneration process by creating a list of tree records describing the new trees on 1/300-acre (0.00135-ha) plots. This simulation is based on predictive equations derived from analysis of almost 5,000 plots (Ferguson and others, manuscript in progress). Tree records are summarized in a table reporting the average probability of stocking for 1/300-acre (0.00135-ha) plots, total trees per acre for each species, identification of best trees from the list of total trees, again by species, and average estimated heights of established seedlings. New tree records are passed to the Prognosis Model where growth and development of the stand are simulated.

To predict regeneration, the current stand inventory is used along with a user-supplied silvicultural prescription. The ways in which the inventory is input and managed over time are explained by Wykoff and others (1982). This report provides a supplement that describes additional options available with the establishment model.

The silvicultural prescription options now available include planting and three types of site preparation: burning, mechanical scarification, and none. Dates of site preparation(s) are controlled by the user, and each can be applied to a specified percentage of the inventory plots. Alternatively, site preparation inventories from individual plots within the stand may be used directly, if desired. The user can also control species planted, year of planting, trees per acre planted, and expected survival. Natural regeneration is predicted independently from the planted trees.

Where the Model is Applicable

Version 1.0 of the Regeneration Establishment Model is calibrated for the grand fir-cedar-hemlock ecosystem in Idaho north of the Salmon River, northeastern Washington, and northwestern Montana. This ecosystem includes the *Abies grandis/Pachistima myrsinites* (grand fir/pachistima), *Thuja plicata/ Pachistima myrsinites* (cedar/pachistima), and *Tsuga heterophylla/ Pachistima myrsinites* (western hemlock/pachistima) habitat types (Daubenmire and Daubenmire 1968).[1] Also included in the present version of the model are predictive equations for the lower elevational limits of the *Abies lasiocarpa/ Pachistima myrsinites* (subalpine fir/pachistima) habitat type. Many of these plots represent ecotones on the lower fringes of the *Abies lasiocarpa/Pachistima myrsinites* habitat type.

These four habitat types are collectively called the Pachistima union. The Pachistima union is a moist upland environment generally found at midelevations within forested areas of the Northern Rocky Mountains. The *Abies grandis/Pachistima myrsinites* habitat type is the warmest and driest of the habitat types in the Pachistima union, with the *Thuja plicata/Pachistima myrsinites* and *Tsuga heterophylla/Pachistima myrsinites* being progressively cooler and wetter. The *Abies lasiocarpa/Pachistima myrsinites* habitat type is the coldest and wettest of the four habitat types represented in the model.

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[1]Habitat type names using *Pachistima myrsinites* or *Clintonia uniflora* are interchangeable. *Pachistima myrsinites* is an indicator plant used by the Daubenmires in their classification system. Other ecologists (Pfister and others 1977; Steele and others 1981) use the herbaceous plant *Clintonia uniflora* to denote the same understory climax community.

HOW THE MODEL WORKS

This section describes some of the general mechanics of the model. The theoretical concepts can be found in Stage and Ferguson (1982) and Ferguson and others (manuscript in progress).

The Prognosis Model can begin simulation using inventory data from any stage in the life of a stand. This feature has been retained in the establishment model. After a disturbance has been simulated, the establishment model can be invoked. (We use the word "disturbance" rather than "cutting" because the opening up of the stand can be caused by many processes other than harvesting.) The regeneration model can represent the status of regeneration at any time from 3 to 20 years after disturbance, with the time specified either by the user or by logic contained in the Prognosis Model.

How the Model Displays Regeneration

Regeneration is reported in two summaries, each called a "tally." A tally is an inventory of the new trees which is passed to the Prognosis Model. The user can specify tally dates in a similar manner that a stand is scheduled for a regeneration inventory at a future date (fig. 1).

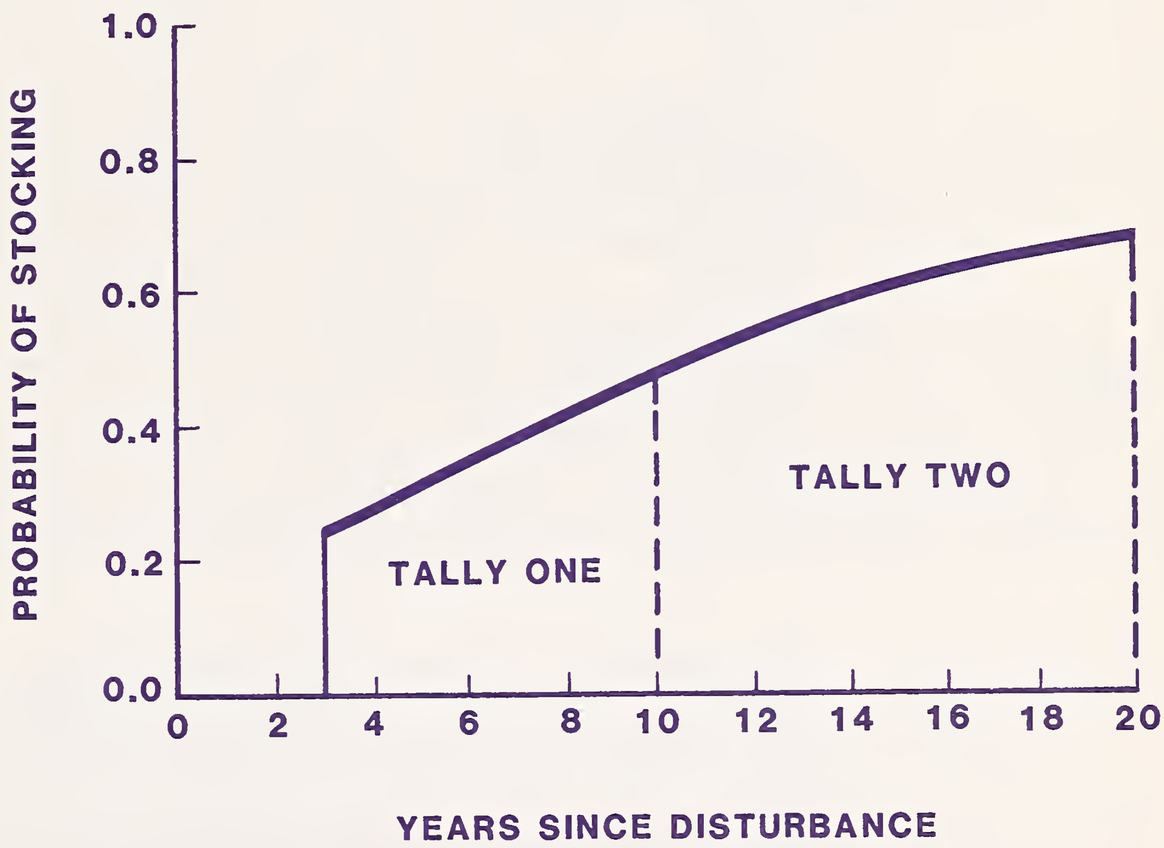

Figure 1. Generalized representation of increased probability of stocking over time for a 1/300-acre (0.00135-ha) plot. Two regeneration tally dates are controlled by the user. The first tally of regeneration can be scheduled between 3 and 10 years since disturbance and the second tally scheduled following the first tally and up to 20 years after disturbance. Default dates are 10 and 20 years since disturbance.

Each tally reports the probability of stocking, total trees per acre by species, a subsample of the best trees in the new stand, and average tree heights. Important independent variables used to predict regeneration include habitat type, aspect, slope percent, site disturbance, topographic position, elevation, time since last disturbance, residual overstory density and species composition, and geographic location. Table 1 provides an overview of how these variables are used.

Table 1.—Summary of dependent and independent variables used in the Regeneration Establishment Model. A ✓ indicates those independent variables used to predict the dependent variable.

	Dependent variable			
Independent variable	**Probability of stocking**	**Number of trees/plot**	**Species composition**	**Tree heights**
Habitat type	✓	✓	✓	✓
Slope	✓	✓	✓	✓
Aspect	✓	✓	✓	✓
Elevation	✓	✓	✓	✓
Topographic position			✓	
Geographic location			✓	
Residual overstory basal area	✓	✓	✓	✓
Residual overstory species composition			✓	
Time since disturbance	✓	✓	✓	✓
Site preparation	✓		✓	✓

The first tally of regeneration can be scheduled at any time between 3 and 10 growing seasons from the year of disturbance. Planting and site preparation can be done during the first tally. Also, surviving advance regeneration will be predicted if these trees are not already in the inventory. Advance trees are those that germinated and became established prior to the disturbance. When a stand inventory has been taken within 20 years of the first summary, it is assumed that advance trees were recorded. If this has not been done, the user may so indicate and the regeneration model will predict this component of the regeneration.

During the first tally, the model also calibrates the probability of stocking to adjust for differences between the actual inventory and the predicted stocking. This feature adjusts the stocking curve (predicted) to coincide with a known reference point (inventory). Obviously a stand already stocked with many trees per acre has little room left for increases in stocking whereas each additional seed germinating in a sparsely stocked stand has a greater probability of establishing a seedling in a nonstocked area.

The second tally describes only regeneration becoming established after the first tally. Site preparation(s) assigned to individual plots in the first tally are the same in the second tally. Regeneration occurring after 20 years is not accounted for until another disturbance takes place, at which time these trees will be introduced as advance regeneration.

Data Requirements

The regeneration model is designed to utilize inventory data from a sample of 1/300-acre (0.00135-ha) circular plots that are representative of the stand. Each plot is projected separately so that the unique qualities of the plot are used in the prediction. Microsite variation among plots within a stand was found to be correlated with regeneration success and this variation seen in nature is retained by predicting outcomes plot by plot. Program logic utilizes stand inventory data in the event that plot values have not been provided. If default stand values are used, each plot within the stand is assigned the appropriate stand value. Thus the degree of resolution for the regeneration model is somewhat controlled by the user.

The number of inventory plots to use as input to the model depends on microsite variation within the stand. A completely homogeneous stand could be represented by one plot, with stand attributes serving as the default values for the regeneration model. An added feature replicates the number of plots until 50 are available for projection. Plot replication insures that plots within the stand vary in such things as number of trees per plot, species composition of seedlings, and initial tree heights.

The use of plot sizes other than 1/300-acre (0.00135 ha) is permissible if the user is willing to assume that site descriptions are applicable. The reported probability of stocking assumes a 1/300-acre (0.00135-ha) plot size; however, conversions to other plot sizes are possible (Wellner 1940; Lynch and Schumacher 1941; Stage 1969).

Another important model concept deals with what we call "best trees." Although we include all established seedlings in the summaries, best trees play a key role in the linkage to the Prognosis Model. The idea of best trees results from the fact that often more trees occupy the growing space than can be expected to produce a commercial product later in the rotation (Wellner 1940). By featuring a few trees on each stocked plot, attention is focused on the growing stock that will contribute to yield. Best trees are chosen by the following rules:

- Select the two tallest trees on each 1/300-acre (0.00135-ha) plot regardless of species.
- Select the tallest one tree of each additional species represented on the plot.
- If the first two rules do not total four trees, select in order of descending height from any remaining trees, if present, until four are chosen.

These rules assume that within each species the tallest trees on the plot are the most likely to survive and grow well. Reporting at least one tree of each species present on the plot also gives a better picture of the distribution of that species throughout the stand. Future predictions about the stand can then account for differing rates of development between species. All best trees are passed to the Prognosis Model for simulation of future stand development and are coded as being "desirable" trees (see tree value class codes, p. 16 and 99 in Wykoff and others 1982). Trees not chosen as best trees are called "excess trees." Up to five excess trees of each species present on the plot are also

passed to the Prognosis Model but are coded as being "acceptable" trees. Thinnings simulated by the Prognosis Model can use these codes to remove acceptable trees before desirable tree records.

Planting of the stand can be scheduled any time prior to the year of the first tally. The user specifies the year of planting, species, trees per acre, and expected survival of each species planted. These trees are added to the inventory just before best trees are selected, thereby allowing planted trees to compete with natural regeneration during the selection process for best trees. Planted trees are coded as "desirable" if chosen as a best tree or "acceptable" if not a best tree.

The reported probability of stocking is for natural regeneration only. Adequate historical records were not available to model plantations using retrospective examination procedures. We feel that model users should have direct control of plantation survival because planting technology can change rapidly, and knowledge of recent experience in an area is irreplaceable.

Inventory Considerations that Improve Predictions

The data for the model were collected by a set of rules on an individual plot-by-plot inventory. Equations are sensitive to variation within a stand. To capture the full power of the model, inventories for use by the regeneration model should:

- Inventory microsite (fixed plot) attributes (slope percent, aspect, site disturbance, habitat type, topographic position, and plot stockability) at each sample point. We used a 1/300-acre (0.00135-ha) circular fixed-area plot.
- Set minimum height requirements for trees to be recorded as established. We recorded trees that were a minimum of 0.5 foot (15 cm) tall if shade tolerant and 1.0 foot tall (30 cm) if shade intolerant (see appendix A). Maximum size for all regeneration was 3.0 inches (7.6 cm) d.b.h.
- Identify best trees on each plot as outlined in the previous section on data requirements.
- Record overstory density and species composition at each plot. Overstory/understory plot identification now needs to be closely coordinated.

EXAMPLE OF REGENERATION ESTIMATES

An example of regeneration model output will show results of cutting the same stand (S248112) used by Wykoff and others (1982). In their example, a shelterwood cutting of 35 trees per acre (86 trees per ha) was simulated. Leave trees were primarily Douglas-fir and grand fir. Stand S248112 is on the St. Joe National Forest at an elevation of 3,400 feet (1 036 m), northwest aspect, 25 to 35 percent slope, and the habitat type is *Tsuga heterophylla/Pachistima myrsinites*. The input records needed to simulate this silvicultural prescription are shown in figure 2.

The regeneration model was invoked by inserting two records into the keyword record file. The first keyword is **ESTAB** with the year of disturbance in field 1 and the second is **END** denoting the end of a packet of establishment keywords. (The use of keywords is explained in the next section.) Output from the regeneration model is shown in figure 3.

```
STDIDENT
S248112  HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL (WITH REGENERATION MODEL)
COMMENT
  THE PRESCRIPTION CALLS FOR IMMEDIATE REMOVAL OF
  EXCESS TREES, A COMMERCIAL THINNING AT AGE 90
  TO REMOVE LODGEPOLE AND LARCH, A SHELTERWOOD
  REGENERATION TREATMENT AT AGE 120 FAVORING
  GRAND FIR AND DOUGLAS-FIR, AND AN OVERWOOD
  REMOVAL AT AGE 130.
END
DESIGN                                         11.0       1.0
STDINFO        18.0     570.0      57.0        8.0        3.0       34.0
INVYEAR      1977.0
NUMCYCLE        8.0
THINPRSC     1980.0     0.999
SPECPREF     2010.0       2.0     999.0
SPECPREF     2010.0       7.0    9999.0
THINBTA      2010.0     157.0
SPECPREF     2040.0       3.0    -999.0
SPECPREF     2040.0       4.0     -99.0
THINBTA      2040.0      35.0
ESTAB        2037.0
END
TREEDATA        5.0
   1      248112       0101   011LP 11510   0734   0011      0  03257021
   2      248112       0102   011WH 06523   0308   0011      0  03157024
   3      248112       0102   031DF 001     0026   0022      0  0
   4      248112       0102   011L  07906   0753   0011      0  0
   5      248112       0102   016L  346            1032      0  0
   6      248112       0103   011L  08007   0633   7322      0 562253022
   7      248112       0103   011GF 06220   0385   0011      0  0
   8      248112       0103   011L  084       54   0011      0  0
   9      248112       0103   011LP 09511   0603   0011      0  0
  10      248112       0104   011DF 040     0203   0011     50  04253031
  11      248112       0104   011L  08212   0655   5011      0  0
  12      248112       0105   011DF 012     0116   0022     42  03452032
  13      248112       0105   011DF 019     0135   0022     47  0
  14      248112       0105   015LP 072            1132      0  0
  15      248112       0105   011C  001     0027   0022      0  0
  16      248112       0105   011GF 05309   0277   0011      0  0
  17      248112       0106   011DF 10010   0654   0011      0  03253023
  18      248112       0106   011GF 06112   0388   0011      0  0
  19      248112       0106   011DF 12716   0674   0011      0  0
  20      248112       0107                          80         4257011
  21      248112       0108   011LP 09605   0603   0022      0  01157021
  22      248112       0108   011DF 10409   0555   7422      0 49
  23      248112       0108   011LP 085       03   0011      0  0
  24      248112       0109   011GF 10910   0657   0011      0  05257024
  25      248112       0109   011DF 09418   0604   0011      0  0
  26      248112       0110   011C  03206   0175   0022     32  03257031
  27      248112       0110   031GF 001     0037   0022      0  0
  28      248112       0110   011C  05810   0287   0011      0  0
  29      248112       0110   011C  05010   0253   0011     37  0
  30      248112       0111   011GF 06614   0307   0011      0  02157031
  31                   -999
PROCESS
STOP
```

Figure 2. Sample keyword record file to project stand S248112 using the combined Prognosis Model/Regeneration Establishment Model.

```
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*                                                                     *
*        REGENERATION ESTABLISHMENT MODEL VERSION 1.0                 *
*                                                                     *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
```

THE PRESCRIPTION FOR STAND: S248112   MANAGEMENT ID: NONE

DATE OF DISTURB-ANCE	SITE PREP, DATE, AND PERCENT						NUMBER OF PLOTS BY HABITAT TYPE			
	NONE	PCT	MECH	PCT	BURN	PCT	520	530	570	620
2037	2037	91	2037	9	2037	0	0	0	11	0

CUMULATIVE PROBABILITY OF STOCKING IS 0.7706 IN THE FALL OF 2046

TALLYONE	ADDITIONAL REGENERATION THIS TALLY.		SUBSAMPLE OF "BEST" TREES REGENERATING DURING THIS TALLY.			REGENERATION(<3"DBH) BEING PROJECTED BY THE PROGNOSIS MODEL.		
SPECIES	TREES /ACRE	% OF TOTAL	TREES /ACRE	% OF TOTAL	AVERAGE HEIGHT	TREES /ACRE	% OF TOTAL	SPECIES
WP	108.	4.	47.	6.	1.7	97.	5.	WP
L	10.	0.	10.	1.	3.8	10.	0.	L
DF	275.	9.	115.	14.	3.0	238.	12.	DF
GF	1365.	46.	277.	34.	3.7	809.	40.	GF
WH	971.	33.	263.	32.	4.3	658.	33.	WH
C	199.	7.	99.	12.	4.6	189.	9.	C
LP	6.	0.	6.	1.	2.0	6.	0.	LP
S	10.	0.	10.	1.	0.5	10.	0.	S
AF	0.	0.	0.	0.	0.0	0.	0.	AF
PP	0.	0.	0.	0.	0.0	0.	0.	PP
	2944.		827.			2018.		

CUMULATIVE PROBABILITY OF STOCKING IS 0.8950 IN THE FALL OF 2056

TALLYTWO	ADDITIONAL REGENERATION THIS TALLY.		SUBSAMPLE OF "BEST" TREES REGENERATING DURING THIS TALLY.			REGENERATION(<3"DBH) BEING PROJECTED BY THE PROGNOSIS MODEL.		
SPECIES	TREES /ACRE	% OF TOTAL	TREES /ACRE	% OF TOTAL	AVERAGE HEIGHT	TREES /ACRE	% OF TOTAL	SPECIES
WP	195.	8.	14.	10.	1.7	174.	6.	WP
L	16.	1.	2.	1.	4.4	11.	0.	L
DF	245.	10.	21.	16.	2.3	309.	10.	DF
GF	1216.	50.	58.	44.	1.6	1408.	46.	GF
WH	643.	27.	33.	25.	2.1	906.	30.	WH
C	70.	3.	4.	3.	1.3	212.	7.	C
LP	0.	0.	0.	0.	0.0	5.	0.	LP
S	27.	1.	0.	0.	1.2	14.	0.	S
AF	0.	0.	0.	0.	0.0	0.	0.	AF
PP	0.	0.	0.	0.	0.0	0.	0.	PP
	2412.		132.			3039.		

Figure 3. Regeneration Establishment Model output. These results are obtained by projecting stand S248112 shown in figure 2.

In the fall of 2046, there are 2,944 total trees per acre (7 275 trees per ha) of which 827 per acre (2 044 per ha) are identified as best trees. The probability of stocking is 0.7706 after 10 growing seasons. There is also a table displaying all trees in the tree list less than 3.0 inches (7.6 cm) d.b.h. that are being projected by the Prognosis Model. These trees can be a mixture of regeneration input by the inventory, best trees passed by the regeneration model, planted trees, and excess trees. In this case, the trees are all best or excess trees. No tree records from the 1977 inventory would be less than 3.0 inches (7.6 cm) d.b.h. in 2046, and no trees were planted in this example.

The second tally is summarized in the fall of 2056 at which time 2,412 more trees per acre (5 960 per ha) regenerate, 132 per acre (326 per ha) of these being best trees. The current regeneration table now contains new trees from the second tally plus trees still in the inventory from the first tally of regeneration.

Model output considers several aspects of the regeneration:

- The probability of stocking, a number between 0.0 and 1.0, indicating the proportion of stocked plots.
- The inventory of total trees per acre, listed by species.
- A summary table of the best trees from the current tally of regeneration.
- The regeneration-size trees currently being projected by the Prognosis Model.

The Prognosis Model summary statistics table for this stand is in figure 4. Regeneration appears in the list of trees/acre in the years 2047 and 2057.

SUMMARY STATISTICS

			VOLUME PER ACRE			REMOVALS PER ACRE						AVE	GROWTH			STAND	IDENTIFIERS	
YEAR	AGE	TREES /ACRE	TOTAL CU FT	MERCH CU FT	MERCH BO FT	TREES /ACRE	TOTAL CU FT	MERCH CU FT	MERCH BO FT	BA/ ACRE SQFT	CCF	OOM HT FT	PRO YRS	ACC CUFT/YR	MOR CUFT/YR	SAMPLE WEIGHT	STANO	MGMT
1977	57	536	1541	1075	2804	296	290	250	645	64	84	64	10	73	7	11	S248112	NONE
1987	67	224	1907	1551	4377	0	0	0	0	85	107	68	10	98	12	11	S248112	NONE
1997	77	210	2768	2450	8289	0	0	0	0	108	130	74	10	122	18	11	S248112	NONE
2007	87	197	3809	3546	14076	40	977	926	3910	104	125	79	10	115	18	11	S248112	NONE
2017	97	148	3803	3591	15583	0	0	0	0	124	142	86	10	149	25	11	S248112	NONE
2027	107	139	5037	4828	22691	0	0	0	0	149	164	93	10	151	33	11	S248112	NONE
2037	117	131	6219	5998	29225	96	4627	4461	21995	42	41	95	10	41	8	11	S248112	NONE
2047	127	2051	1922	1864	9145	0	0	0	0	49	52	89	10	42	10	11	S248112	NONE
2057	137	3070	2249	2161	10958	0	0	0	0	57	64	93	0	0	0	11	S248112	NONE

ACTIVITY SUMMARY

STANO IO= S248112 MANAGEMENT IO= NONE HYPOTHETICAL PRESCRIPTION FOR USER'S MANUAL (WITH REGENERATION MODEL)

CYCLE	DATE	EXTENSION	KEYWORD	OATE	ACTIVITY OISPOSITION	PARAMETERS:			
1	1977								
		BASE	THINPRSC	1980	OONE IN 1977	1.00			
2	1987								
3	1997								
4	2007								
		BASE	SPECPREF	2010	OONE IN 2007	2.00	999.00		
		BASE	SPECPREF	2010	OONE IN 2007	7.00	9999.00		
		BASE	THINBTA	2010	DONE IN 2007	157.00	0.98	0.0	999.00
5	2017								
6	2027								
7	2037								
		BASE	SPECPREF	2040	OONE IN 2037	3.00	-999.00		
		BASE	SPECPREF	2040	OONE IN 2037	4.00	-99.00		
		BASE	THINBTA	2040	OONE IN 2037	35.00	0.98	0.0	999.00
		ESTB	TALLYONE	2046	OONE IN 2046	2037.00			
8	2047								
		ESTB	TALLYTWO	2056	OONE IN 2056	2037.00			

Figure 4. Summary tables from projecting stand S248112 with the combined Prognosis Model/Regeneration Establishment Model. The stand was projected using the silvicultural prescription shown in figure 2. Regeneration appears in the tree list in the years 2047 and 2057.

How to Enter Your Information

The regeneration model is controlled through the use of keywords. The keyword system is explained by Wykoff and others (1982); only those keywords pertinent to understanding the regeneration model are explained in this paper.

The first keyword in the regeneration list is always **ESTAB**, and the last one is always **END**. The **ESTAB** keyword means that records to follow are for the regeneration extension, and the **END** keyword signifies the end of regeneration keywords. Each keyword is left-justified in the first 10 columns of the record. The next seven 10-column fields, called parameter fields, are used to transmit numeric data. Numeric data should include a decimal point or be right-justified within the parameter field if no decimal is included. Not all seven fields are used on every keyword record.

Table 2 lists keywords and parameter fields for the establishment extension. Keywords fall into three general classes—those used to specify silvicultural

Table 2.—Keywords and parameter fields specific to the regeneration establishment extension.

	Parameter fields			
Keyword	1	2	3	4
ESTAB	year of disturbance			
PLANT	year of planting	species code	trees per acre	percent survival
BURNPREP	year of burning	percent burned		
MECHPREP	year of scarifying	percent scarified		
TALLYONE	year of summary	optional year of disturbance		
TALLYTWO	year of summary	optional year of disturbance		
EZCRUISE				
PLOTINFO	external dataset number, if used			
OUTPUT	level			
RESETAGE	year to reset stand age	new age		
DATELIST				
RANNSEED	new seed			
SPECMULT	year multiplier takes effect	species code	multiplier	
STOCKADJ	year multiplier takes effect	multiplier		
HTADJ	year value takes effect	species code	adjustment value	
END				

prescriptions, those for program control, and prediction modifiers. We have shown some sample keyword packets in appendix C. Use of regeneration model keywords follows.

ESTAB The **ESTAB** keyword is used to enter the year of disturbance and to signal that the keywords to follow are for the regeneration extension.

field 1: Year of disturbance. This year corresponds to the year the cutting was simulated. Some care is necessary to insure that the year of disturbance in this field corresponds to the cycle boundary of the harvest simulation as reported by the Prognosis Model. Examine the example shown in figure 2 and figure 4. The **THINBTA** cutting specified for the year 2040 was accomplished in 2037. This is why the year 2037 was specified on the **ESTAB** keyword record. The Prognosis Model will automatically schedule calls to the regeneration model at 10 and 20 growing seasons after the year in field 1. If output is desired at times other than 10 and 20 growing seasons, use the keywords **TALLYONE** and **TALLYTWO** to specify output years.

PLANT Specifies that planting is to be simulated. A separate **PLANT** record is necessary for each species planted. Planted trees are an addition to natural regeneration but do compete with naturals in the best tree selection process. The **STOCKADJ** keyword can be used in conjunction with planting to suppress natural regeneration so that only planted trees are passed to the Prognosis Model.

field 1: Year the planting is to be done. Planting can be simulated any time prior to the first regeneration tally date.

field 2: Species code for planted trees. Refer to appendix A for numeric species codes.

field 3: Number of trees per acre to be planted for the species indicated in field 2.

field 4: Expected survival for this species, expressed as a percentage, at the time of the first tally date. If field 4 is blank, survival will be 100 percent. The time period to use for calculating survival is from the year of planting to the year of the first tally plus one year. Example: The stand is cut in 1980, planted in 1982, and the first tally of regeneration is scheduled for the fall of 1989. The number of growing seasons (assuming spring planting) is 1989 − 1982 + 1 = 8.

BURNPREP
MECHPREP

Three types of site preparation can be selected: burning, mechanical scarification, and no disturbance. Each inventory plot receives one site preparation method. (If desired, site preparations can be assigned to individual plots. See discussion of the **PLOTINFO** keyword and the section entitled Prognosis Model Version 5.0.)

When site preparation treatments have not been specified or assigned, default equations are invoked. These equations predict the proportion of the stand receiving each of the three treatments based on site characteristics such as slope, aspect, habitat type, residual basal area, elevation, and topographic position. Data used to calibrate these equations were from stands not treated by post-harvest scarification or broadcast burning and reflect historical trends in the grand fir-cedar-hemlock ecosystem for the period 1960 through 1972.

The **BURNPREP** keyword is for burning and **MECHPREP** for mechanical scarification. The sum of mechanical and burn treatments must be less than, or equal to, 100 percent. If the sum is less than 100 percent, the difference will be the percentage of plots that are undisturbed.

field 1: Year of site preparation.

field 2: Percentage of plots to be treated. Default is 0.0.

TALLYONE
TALLYTWO

The **TALLYONE** and **TALLYTWO** keywords can be used to schedule regeneration summaries other than at 10 and 20 growing seasons after a disturbance. A **TALLYONE** keyword can specify output at years between 3 to 10 growing seasons after the disturbance. **TALLYTWO** can be specified any time after the **TALLYONE** record up to 20 growing seasons after disturbance. **TALLYONE** and **TALLYTWO** dates must fall within the cycle regeneration is desired. Regeneration is reported at the end of that cycle and is predicted using the number of elapsed growing seasons. Therefore, a stand cut in 2040 has five growing seasons if the next cycle begins in 2045. The first tally of regeneration would be reported in the fall of 2044 in this case. When a **TALLYONE** keyword is used, the second tally of regeneration is not automatically scheduled. To get the second tally, a **TALLYTWO** keyword record is necessary.

field 1: Year the tally of regeneration is passed to the Prognosis Model and the summary printed.

field 2: An optional field to supply a year of disturbance which takes precedence over the year of disturbance entered in field 1 of the **ESTAB** keyword record. Thus it is possible to schedule more than one **TALLYONE** or more than one **TALLYTWO** in the same packet of regeneration keywords.

EZCRUISE We assume that the inventory supplied by the user includes any regeneration presently in the stand. This assumption was necessary because it is not possible to distinguish between an inventory design that does not count small trees and one that does, but no small trees were found. If the inventory did not record small trees, use this keyword to let the model predict the small tree component at the time of the inventory. This prediction will be a mixture of advance and subsequent regeneration depending on the number of years since the last disturbance. Program logic keeps track of the last time the advance component of regeneration was accounted for. Whenever 20 years have elapsed and a **TALLYONE** is scheduled, advance regeneration will be added to the inventory. Therefore the **EZCRUISE** keyword needs to be used only during the first 20 years since the stand inventory and only if trees under 3.0 inches d.b.h. were not recorded. No parameter fields are associated with this keyword.

PLOTINFO Plot variables can be entered with the **PLOTINFO** keyword which initiates the reading of individual plot records to obtain values for slope, aspect, habitat type, etc.

field 1: The value in this field defines where supplemental data records are found. When blank, supplemental data records are assumed to follow. If there is a positive number in field 1, it is accepted as a reference number indicating a dataset on which the plot records are stored.

Supplemental data records following the **PLOTINFO** keyword must contain one record per plot. From each record is read plot identification, slope percent, aspect, habitat type, topographic position, and site preparation. Columns for plot characteristics are listed below and numeric codes are listed in appendix B.

Columns 1-10: Plot identification number coded the same as variable **ITRE** in the Prognosis Model. A card with **ITRE** coded as any negative number denotes the end of **PLOTINFO** supplemental data records and must be present. See the example in appendix C.

Column 11: Slope percent code.

Column 12: Aspect code.

Columns 13-15: Habitat type code.

Column 16: Topographic position.

Column 17: Site preparation. In addition to none, mechanical scarification, and burning, it is possible to record if the plot falls on a road cut, road fill, or road bed of roads available for regeneration.

OUTPUT A keyword used to control the kind of printed output desired from the regeneration model. The **OUTPUT** keyword need not be used except to change the default output shown in figure 3.

field 1: Numeric code for the level of printed output desired. Code "0" suppresses all output, but new tree records are still passed to the Prognosis Model. Code "1" is the default output shown in figure 3. Code "2" prints program calculations as they occur in the regeneration model and is helpful to debug projections that encounter problems. A great deal of computer printing results from this option. Code "3" will print the table shown in figure 3 plus a plot summary table. The plot summary table shows plot-by-plot values for slope, aspect, habitat type, site disturbance, topographic position, residual overstory density by species, and stocking increments. This table is helpful to insure that **PLOTINFO** values were correctly interpreted by the regeneration model.

RESETAGE Stand age can be reset to make Prognosis Model output correspond to the age of the new stand.

field 1: Year or cycle that age is to be reset (usually the year of disturbance). Default is 1.0.

field 2: New stand age; default is 0.0.

DATELIST This keyword is used to print the date of last revision for subroutines and common areas used by the establishment model. Note that this keyword is also a Prognosis Model keyword when used before or after a packet of regeneration keywords. No parameter fields are associated with this keyword.

RANNSEED The Regeneration Establishment Model uses a separate pseudorandom number generator which can be reseeded independently of the pseudorandom number generator used by the Prognosis Model. This keyword is also a Prognosis Model keyword when used before or after a packet of regeneration keywords.

field 1: Replacement value for the seed. If blank, the default seed is displayed.

Model Modifications

The next three keywords (**SPECMULT**, **STOCKADJ**, and **HTADJ**) are included for users who find the need to simulate conditions not represented by the regeneration model. Some examples would be new treatments such as control of competing vegetation, advances in regeneration technology, or simulation of pest or disease conditions. These keywords should be used with caution because results of the projection depend upon the assumptions you, the user, make.

These keywords are invoked at user-specified years and remain in effect unless changed later.

SPECMULT A species-specific multiplier that expands or contracts the probability of a species' occurrence. As an example, this keyword could be used to simulate increases in a species' probability attributable to protection of the cone crop or decreases in a species' probability due to a host-specific forest pest. One keyword record is needed for each species to be modified. The multiplier does not set the probability of a species' occurrence; it is multiplied by the probability to increase or decrease the probability. A multiplier of 1.0 has no effect on the probability for that species.

field 1: The year the multiplier takes effect.

field 2: Numeric species code to which the multiplier will be applied.

field 3: Multiplier for the regeneration model to use.

STOCKADJ A multiplier used to adjust the probability of stocking equation upward or downward. It could be used to simulate increases in stocking due to changing technology or decreases in stocking due to adverse actions such as forest pests, soil compaction, livestock grazing, etc. The probability of stocking is a sigmoid curve (fig. 1), the result of a nonlinear logistic model form (Hamilton 1974). The probability of stocking will be multiplied by the value entered in field 2 of the keyword record. However, the product will not exceed the bounds of the interval [0,1].

field 1: The year the multiplier takes effect.

field 2: Multiplier for the probability of stocking. This value is easily calculated by dividing the desired probability of stocking by the predicted probability of stocking. As an example, suppose that the regeneration model reports the probability of stocking 10 growing seasons after a harvest is 0.40 and it is desired to raise this figure to 0.50 in a subsequent run. The value to enter in field 2 is:

$$\frac{\text{desired stocking}}{\text{reported stocking}} = \frac{0.50}{0.40} = 1.25$$

If field 2 is blank or zero, natural regeneration is canceled so that only planted trees regenerate. This can be helpful in simulating growth of plantations or to input a list of trees on a habitat type that the regeneration model cannot presently represent.

HTADJ A species-specific keyword used to modify the initial established height of trees before the tree records are passed to the Prognosis Model. Its use should not be confused with the Prognosis Model keyword **REGHMULT**, which is a multiplier. The adjustment can be positive or negative depending on the situation being simulated, but assigned heights will not be less than the minimum establishment heights listed in appendix A.

field 1: The year adjustment value takes effect.

field 2: Code for the species to which the value in field 3 will be applied.

field 3: Value (feet) to be added to or subtracted from the height of each tree record generated by the regeneration model.

END Signifies the end of a packet of keywords for the regeneration extension. Program control is returned to the Prognosis Model.

Variation in Regeneration Estimates

The regeneration model contains logic that reproduces plot-to-plot variation in the number of trees per plot, species composition, and initial tree heights. Stand statistics are the average of plot conditions and a large number of plots lessens the influences of infrequent occurrences. Currently, plots are replicated by repeated doubling until at least 50 are available for projection. Even though plots are replicated, some differences between runs can be expected when the calling sequence to the pseudorandom number generator is changed.

We have explored this variation for the stand used to develop examples in this user's manual. The pseudorandom number generator was reseeded in 5 additional runs using the **RANNSEED** keyword. New six-digit seeds were chosen from a table of random numbers. Summaries of the best trees passed to the Prognosis Model are shown in Table 3. Total numbers of best trees ranged from 776 to 844 trees per acre (1 917 to 2 086 trees per ha). Species composition of best trees varies slightly, but the overall pattern of species represented remains the same.

Table 3.—Sample projections of stand S248112 with the pseudorandom number generator reseeded. The 11 plots were replicated 5 times. Cells contain the number of best trees per acre by species and projection. The default seed is 55329.

	Pseudorandom number generator seed					
Species	Default	244349	112061	313169	008827	937763
	Best trees per acre					
WP	47	70	37	90	50	59
L	10	10	0	10	0	3
DF	115	99	110	75	96	100
GF	277	290	319	250	279	345
WH	263	212	272	289	244	226
C	99	93	86	73	80	59
LP	6	7	10	7	20	7
S	10	0	7	3	0	3
AF	0	0	3	16	7	7
PP	0	0	0	0	0	0
Totals	*827*	*781*	*844*	*813*	*776*	*809*

Some variability between runs was controlled by setting the maximum number of tallied trees to 33 per 1/300-acre (0.00135-ha) plot. This maximum was chosen because 95 percent of all stocked plots in the data used to develop the regeneration model had 33 or fewer trees per plot.

Species compositions may change depending on when tally dates are specified. With increasing time, some species can increase in probability while others may have a static or decreasing probability. Boyd (1969) has shown case histories where species compositions changed within the same stand at different sampling dates.

PROGNOSIS MODEL VERSION 5.0

The Regeneration Establishment Model is available with Version 5.0 of the Prognosis Model. This revision has several improvements over Version 4.0 that facilitate the regeneration extension. In particular, modeling of growth rates of trees less than 3.0 inches d.b.h. has been revised.

All Prognosis Model keywords that have a field for cutting efficiency have been modified. The cutting efficiency parameter can now be set to 1.0. Previously, the largest proportion of a tree that could be removed was 0.99. Total tree removal will better simulate clearcutting or overstory removal.

A tree list is no longer necessary to begin projection. A new Prognosis Model keyword called **NOTREES** can be used to indicate when there are no projectable tree records. It is important to note that **NOTREES** is a Prognosis Model keyword and needs to appear before or after the packet of regeneration keywords. There are no parameter fields associated with this keyword.

Plot-specific microsite conditions can be read directly from the tree record file. This information must be contained on the first tree record for each plot and coded as shown in appendix B. Figure 1 shows plot variables coded on the tree record file. The default format for tree records is as shown by Wykoff and others (1982, page 17). When a positive number is coded in field 2 of the **TREEDATA** keyword record, variables 14 through 18 shown in appendix B will also be read from the tree record file. If variables 1 through 13 are coded in the columns specified by Wykoff and others (1982, page 17) and variables 14 through 18 are coded as shown in appendix B, a new tree record format (**TREEFMT**) is not necessary. However, some care is necessary if a **TREEFMT** keyword record is used to specify a format statement. When a **TREEFMT** record is present and field 2 of the **TREEDATA** keyword contains a positive number, 18 variables must be accounted for in the format statement.

Version 5.0 has a feature that automatically combines similar tree records so that the number of tree records does not exceed available computer storage when the regeneration model is called. Whether or not the compression subroutine is called should not materially affect projections. Whenever it is invoked, it will be reported in the activity summary using the keyword **COMPRESS**.

The last enhancement of importance to regeneration model users is an extension called the Event Monitor (Crookston, in preparation). The event monitor detects when a user-specified event has occurred and then schedules a user-specified course of events. This extension provides some flexibility for scheduling calls to the regeneration model when the year of disturbance is not known. As an example, the Prognosis Model may be operating under automatic stocking control (**THINAUTO**). The user may wish to display the regeneration occurring after a heavy thinning. The event monitor can detect the thinning when it happens and schedule the correct calls to the regeneration extension.

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APPENDIX A

Scientific Name, Common Name, Numeric Code, and Minimum Establishment Height for Regeneration

Scientific name	Common name	Code	Minimum height	
			Feet	*cm*
Pinus monticola Dougl.	western white pine	1.0	1.0	30
Larix occidentalis Nutt.	western larch	2.0	1.0	30
Pseudotsuga menziesii var. *glauca* (Beissn.) Franco	Douglas-fir	3.0	1.0	30
Abies grandis (Dougl.) Lindl	grand fir	4.0	.5	15
Tsuga heterophylla (Raf.) Sarg.	western hemlock	5.0	.5	15
Thuja plicata Donn.	western redcedar	6.0	.5	15
Pinus contorta Dougl.	lodgepole pine	7.0	1.0	30
Picea engelmannii Parry	Engelmann spruce	8.0	.5	15
Abies lasiocarpa (Hook.) Nutt.	subalpine fir	9.0	.5	15
Pinus ponderosa Laws. var. *ponderosa*	Ponderosa pine	10.0	1.0	30

APPENDIX B

Codes and Formating Instructions for Recording Plot Variables

Plot data (variable number)	Column(s) if PLOTINFO record	Column(s) if on tree record file	Codes	
Identification number (1)	1 – 10	24 – 27	Assign the same numeric code to corresponding fixed-area and variable-radius plots (right justify).	
Slope percent (14)	11	66	0 = 0–5 1 = 6–15 2 = 16–25 3 = 26–35 4 = 36–45	5 = 46–55 6 = 56–65 7 = 66–75 8 = 76–85 9 = ≥86
Aspect (15)	12	67	1 = north 2 = northeast 3 = east 4 = southeast 5 = south	6 = southwest 7 = west 8 = northwest 9 = level or rolling
Habitat type (16)	13-15	68 – 70	520 = grand fir/pachistima (default for all habitat types coded 520 or less) 530 = cedar/pachistima (default for all cedar habitat types) 570 = western hemlock/pachistima (default for all western hemlock habitat types) 620 = subalpine fir/pachistima (default for all habitat types coded 600 or higher)	
Topographic position (17)	16	71	1 = bottom 2 = lower slope 3 = midslope	4 = upper slope 5 = ridgetop
Site preparation (18)	17	72	1 = none 2 = mechanical 3 = burn 4 = road cuts, road fills, and road beds of unmaintained roads	

APPENDIX C

Examples of Keyword Records for the Regeneration Establishment Model

---

Simplest call to the regeneration model. Stand is disturbed in 2040.

```
ESTAB       2040.0
END
```

Stand is disturbed in 2040. Plant 350 Douglas-fir trees per acre in 2042. Expected survival is 60 percent. Plant 100 western white pine per acre in 2042 with 75 percent survival rate.

```
ESTAB       2040.0
PLANT       2042.0      3.0      350.0      60.0
PLANT       2042.0      1.0      100.0      75.0
END
```

Stand is disturbed in 2040. Natural regeneration is desired and the stand is to be burned in 2041. Estimate 80 percent burn of the stand.

```
ESTAB       2040.0
BURNPREP    2041.0      80.0
END
```

Stand is disturbed in 2040; burn 50 percent of the area in 2041 and scarify another 20 percent in 2042. Then plant 300 western larch per acre in 2043, 45 percent survival.

```
ESTAB       2040.0
BURNPREP    2041.0      50.0
MECHPREP    2042.0      20.0
PLANT       2043.0      2.0      300.0      45.0
END
```

Inventory was taken in 1980 but small trees were not recorded. Harvest is to be simulated in 1990.

```
ESTAB       1990.0
EZCRUISE
END
```

Individual plot records are read in. Harvest year is 1990. Also plant 200 ponderosa pine per acre in 1991, all of them surviving.

```
ESTAB       1990.0
PLOTINFO
       01013257021
       01023157024
       01032253022
       01044253031
       01053452032
       01063253023
       01074257011
       01081157021
       01095257024
       01103257031
       01112157031
       -999
PLANT       1991.0      10.      200.0
END
```

Output is desired 5 growing seasons after a harvest in 1990. The second tally is needed at 15 years. The Prognosis Model is projecting at 10-year intervals so a short cycle of 5 years is needed to make regeneration summary output dates correspond to cycle boundaries. This is done by using the TIMEINT keyword. TIMEINT is a Prognosis Model keyword so it must appear somewhere before or after the packet of regeneration keywords.

```
TIMEINT        2.0       5.0
ESTAB       1990.0
TALLYONE    1994.0
TALLYTWO    2004.0
END
```

Same prescription as before, but the larch casebearer has been successfully controlled by parasites which triples the probability of larch regeneration. The larch regeneration is also 1.5 feet taller.

```
TIMEINT        2.0       5.0
ESTAB       1990.0
TALLYONE    1994.0
TALLYTWO    2004.0
SPECMULT    1990.0       2.0       3.0
HTADJ       1990.0       2.0       1.5
END
```

The effect of defoliation by the Douglas-fir tussock moth is to be simulated. As an example, suppose current research indicates that an infestation decreases the probability of stocking by 10 percent. Further assume that the stand was projected without any changes to the probability of stocking, and at the end of the first cycle, stocking was 50 percent. The multiplier for field 2 of the STOCKADJ keyword record would be the target probability of stocking (40 percent) divided by the probability of stocking reported by the regeneration model (50 percent) or 40/50 = 0.80. Additionally, the tussock moth, being host-specific, decreases the probability of Douglas-fir regeneration by 20 percent, that of grand fir by 50 percent, and subalpine fir by 25 percent. Therefore, the probability of Douglas-fir is 80 percent of its predicted value, grand fir is 50 percent, and subalpine fir 75 percent. All percentages just discussed need to be entered as ratios on keyword records.

```
ESTAB       1990.0
STOCKADJ    1990.0       0.8
SPECMULT    1990.0       3.0       0.80
SPECMULT    1990.0       4.0       0.50
SPECMULT    1990.0       9.0       0.75
END
```

Sometimes it may be desirable to project only the planted trees in the new stand. This can be accomplished with a STOCKADJ keyword having a zero or negative value in field 2 combined with the desired planting.

```
ESTAB       1990.0
STOCKADJ    1990.0       0.0
PLANT       1991.0       4.0       350.0
END
```

Ferguson, Dennis E.; Crookston, Nicholas L. User's guide to the Regeneration Establishment Model—a Prognosis Model extension. General Technical Report INT-161. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 23 p.

This paper documents use of the Regeneration Establishment Model, a computer-based simulator designed to be used as a submodel of the Prognosis Model. Regeneration is predicted following harvesting and site preparation operations. Model characteristics, prescription options, program control, and regeneration summaries are discussed.

KEYWORDS: succession, stand simulation, Northern Rocky Mountains

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